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CASTING OF STEEL STRIP USING A SINGLE ROLL CASTER

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FOUNDRY SECTION

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CASTING OF STEEL STRIP USING A SINGLE ROLL CASTER

by

M. Sahoo, G. Morin and D. Cousineau

ABSTRACT

This report describes the design of a single wheel strip caster and the successful production of both ferrous and non-ferrous strips in the thickness range of 1-3 mm.

LABORATOIRES DE TECHNOLOGIE DES MÉTAUX
RAPPORT: MTL 88-40(TR)

COULÉE CONTINUE DE BANDE D'ACIER À L'AIDE D'UN ROULEAU SIMPLE

par

M. Sahoo, G. Morin et D. Cousineau

RÉSUMÉ

Ce rapport explique le design et l'opération de la machine à coulée continue à simple rouleau et la production de bande de materiaux ferreux et non-ferreux d'épaiseur variant entre 1 et 3 mm.

INTRODUCTION

Steel industries around the world are looking at different approaches to moving directly from the liquid steel stage to the final product. The direct casting of thin metal strip is one such approach since it offers the prospect of greatly decreasing the cost of the final product. This process has the potential to eliminate many process steps such as slab casting, conditioning, reheating, roughing, hot finishing, etc., which are needed in conventional processes to produce strip. The elimination of these process steps reduces energy requirements and significantly lowers the processing costs. Consequently, the Canadian Steel Industries Research Association (CSIRA) has developed a business plan for a new corporation "Bessemer Inc." with the mandate to develop a "made-in-Canada strip-casting technology" enabling the Canadian steel industry to compete with the third world low-cast producers.

This report describes the design of a simple strip-casting machine to produce strips of steel in the thickness range 0.5 to 2.0 mm. In view of the success achieved by Allegheny Ludlum in producing 304 stainless steel strip using a single-roll process (1-4), it was decided to build a simple single-roll strip caster to get acquainted with the strip-casting process. This report gives a brief description of the casting machine and the results achieved in producing strip from various non-ferrous and ferrous metals.

CASTING MACHINE

The strip casting machine built at CANMET uses a single copper wheel 24 cm in diam. and 15 cm wide. The wheel was cut from a continuously-cast electrolytic tough pitch copper ingot. A variable speed electric motor with reducing gear box permits adjustment of the casting speed up to 80 cm/s. Figure 1 is a schematic representation of the single roll strip caster which shows the pouring ladle, tundish and the copper wheel.

A unique tundish design was used to feed liquid metal onto the casting wheel. A sketch of this tundish is shown in Fig. 2. The tundish was made from zircon sand (AFS #120) and a sodium silicate binder. The tundish is a rectangular box divided into two compartments. There is a 1 cm slot at the base of the dividing wall through which liquid metal flows quietly onto the copper wheel. The box is ground with sand paper in such a way that it fits against the copper wheel with minimum clearance. Figure 3 shows the copper wheel and the tundish. The tundish is raised to a higher level in this figure to show the inner details. The entire strip-casting unit is shown in Fig. 4.

A protective cover was designed to carry out strip casting under an argon atmosphere. This cover, shown in Fig. 5, has two glass windows through which the strip casting operation can be observed. The cover surrounds the upper part of the copper wheel and part of the tundish (see

Fig. 6). Figure 7 shows the strip-casting machine in operation while producing 304 stainless steel strips under an argon atmosphere.

In order to improve the surface finish of the top surface of the cast strip, a small brass wheel (10 cm diam. and 16 cm long) was spring mounted as shown in Fig. 8. The gap between the copper wheel and the brass wheel can be adjusted depending on the thickness of the strip. The distance between the lip of the tundish and the nip of the brass wheel is about 10 cm. Figures 9(a) and (b) show the strip casting unit along with the top brass wheel, argon cover and the tundish.

WATER-COOLED WHEEL

A water-cooled wheel assembly (not yet in operation) has been built for strip casting. It will have four parts: a supporting shaft, the copper wheel and two flanges to fit on either side of the copper wheel. The shaft has three functions; it (i) supports the wheel, (ii) transfers the rotational motion and (iii) carries the cooling water. Water is introduced through a stainless steel pipe 66 cm long, 32 mm O.D. and 19 mm I.D. threaded at both ends to fit the rotating unions attached to the shaft. Cooling water flows through 18 channels, 13 mm diam., located around the periphery of the wheel and 25 mm below its surface. These channels are shown in detail in Figs. 10(a) and (b). Two brass flanges are bolted on each side of the copper wheel. The flanges are shaped to permit the water coming from the shaft to reach the cooling channels at the periphery of the copper wheel.

Water flow in the wheel is about 56 L/min [14 gal(US)/min] at a pressure of 0.45 MPa (65 psi). Water velocity in the cooling channel is estimated to be 38 cm/s.

A new strip-casting unit, similar to that in Fig. 4, is being built to incorporate the water-cooled wheel.

CASTING PROCESS

NON-FERROUS METALS

In order to gain confidence and become familiar with the operation of the single-roll strip caster, preliminary test runs were made using non-ferrous metals such as Zn-11% Al [melting point (mp) of 420°C], Al-12% Si (mp of 575°C) and Cu-Ni-Sn (mp of 1050-1150°C, depending on Ni and Sn contents) alloys. The first strip casting was done using the lowest melting alloy (Zn-11% Al) followed by Al-Si and then Cu-Ni-Sn alloys. These alloys were melted in a push-up induction furnace using a clay-graphite crucible. The crucible was lifted at the desired temperature and poured slowly into the tundish. The crucible was lifted at 450°C for Zn-11% Al alloy, 645°C for Al-12% Si alloys, 1275°C for Cu-15% Ni-8% Sn alloys (mp ≈1130°C), 1220°C for Cu-9 Ni-6 Sn alloys (mp ≈1130°C) 1250°C for Cu-9 Ni-2 Sn alloys (mp ≈1125°C) and 1250°C for Cu-4 Ni-4 Sn alloys (mp ≈1070°C). No difficulty was experienced in producing strips of these alloys. The

thickness of the strips varied between 0.5 and 1.5 mm. The width of the strip was about 11 cm and did not change during the casting operation, and the length of the strip produced varied with the alloy. In the case of Al-Si alloys, 20 to 30 m could be produced without any problem. However, in the case of high melting point Cu-Ni-Sn alloys, it was difficult to pull the strip (at present there is no coiler to coil the strips). The strips broke up during pulling probably due to low hot strength. Despite this, strips 4 to 5 m long have been produced. Some of the strips showed oxidized surfaces. Gas holes, surface cracks, etc, were also observed.

Following the production of steel strips (see below), attempts were made to produce strips for Noranda Metals in three types of copper-base alloys: commercial bronze (90/10 brass or alloy C2200), phosphor bronze (Cu-7% Sn or alloy C5100) and cartridge brass (70/30 brass or alloy C2600). Melting points for the three alloys are 1045°C for commercial bronze, 1050°C for phospher bronze and 955°C for cartridge brass.

Of the three alloys, it was relatively difficult to produce strips in C5100. The liquid metal froze quickly at the wheel, and it was not easy to pull the strips because they frequently broke up. Despite such problems, strips up to 3 mm thick have been produced in this alloy. It was discovered, while casting strips in these three alloys, that it was easy to produce strips after the wheel was being heated because of the liquid metal. This led to casting trials using preheated (~70°C) copper and brass wheels. It was relatively easy to produce strips when the wheels were preheated.

FERROUS METALS

The steel was melted in a coreless induction furnace lined with magnesia, tapped into pre-heated ladles and then poured into the tundish. About 25 kg of steel was melted for each run. The first two attempts to cast aluminum-killed low-carbon steel were unsuccessful as the steel froze on the copper wheel. It must be remembered that neither the tundish nor the copper wheel was preheated. This alloy has a melting point of about 1510°C and even tapping the steel at about 1690°C did not help to produce strips.

It was then decided to switch to 304 stainless steel (mp ≈1440°C). In the first attempt, the steel was tapped at 1625°C. However, it froze at the wheel and no strip was produced. Increasing the steel tapping temperature to 1645°C helped to produce 5-6 m of strip. Following this process, a number of attempts were made to produce 304 stainless steel strips. The various casting parameters are listed in Table 1. The object was to increase the thickness of the strip. As shown in Table 1, in case of SR #16, a strip thickness of 2 mm was achieved by reducing the speed of the copper wheel. It may be noted that an alumina refractory sheet was placed at the tip of the tundish which probably helped to keep the steel molten for a longer time.

Following the success with stainless steel, aluminum-killed low-carbon steel was again tried and the tapping temperature was increased to 1700°C. This resulted in a few metres of steel

strip being produced. As shown in Table 1, steel strips were produced even when the steel was tapped at 1680°C. Neither stainless steel nor low-carbon steel strips have been produced yet using preheated wheels.

CHEMICAL COMPOSITIONS

Chemical analyses of the strips are given in Table 2 together with the desired composition ranges. It is evident that, in the case of 304 stainless steel, the carbon content of the strips should be reduced to <0.08% and the Cr and Ni contents should be increased by at least 1%, to meet the specifications. In the case of low-carbon steels, the C, Mn and Al contents should not exceed 0.05, 0.3 and 0.05%, respectively. Table 1 indicates that the aluminum content of the strips is too high.

MICROSTRUCTURE

STAINLESS STEEL

Optical micrographs of the transverse sections of the 304 stainless steel strips are shown in Figs. 11-13. Very fine dendritic structures are observed on the surface in contact with the copper wheel. In some cases, "sunburst" type structures [Fig. 11(b)] were observed. Microstructure of the top surface of the strip exposed to the atmosphere were relatively coarse and consisted of a cellular structure. Comparison of Figs. 12(b) and 13(b) indicates that as the strip thickness increases, the secondary dendrite arm spacing (DAS) decreases because of a decrease in the cooling rate. DAS for these two micrographs was of the order of 5 μm for Fig. 12(b) and 12 μm for Fig. 13(b). The cooling rates for the strips were estimated from such DAS values to be about 6×10^5 °C/s for the 1 mm thick and 6×10^4 °C/s for the 2 mm thick strips.

Examination of the Fe-Cr-Ni phase diagram (Fig. 16) indicates that the cast structure should consist of dendrites of austenite with intercellular delta-ferrite cores. The volume fraction of the austenite and ferrite phases is governed by the strip composition and cooling rate.

Electron probe analyses characterizing the distribution of Ni and Cr across dendritic and interdendritic areas are shown in Figs. 14 and 15 for the thin and thick sections respectively in Run #16. The variation of chromium and nickel contents across the thickness of the strip is given in Table 3. The segregation of Cr and Ni in the as-cast and thermomechanically-processed strips are being examined in detail.

LOW-CARBON STEEL

Optical micrographs of the aluminum-killed low-carbon steels are presented in Figs. 16 and 17. A dendritic structure, similar to that of stainless steel, was not obtained in such low-

carbon steels. Both elongated and equiaxed ferritic grains were observed throughout the thickness of the strip. As would be expected, microstructure of the strip in contact with the wheel was finer than that of the upper surface.

CONCLUSIONS

1. A single-roll strip caster has been designed to produce strips in both ferrous and non-ferrous alloys in the thickness range 1-3 mm.
2. A small brass wheel has been added to the strip caster to produce smoother surfaces.
3. A water-cooled wheel has been designed, but it is not yet in operation.
4. Although strips of type 304 stainless steel and aluminum-killed low-carbon steel have been produced in the single-roll caster, considerable work is still needed in regard to composition control, improvement in surface quality, control of strip thickness, better tundish design, thermomechanical processing, etc.

ACKNOWLEDGEMENTS

Our special thanks to the foundry support staff for their cooperation during tundish design, melting and casting. Technical assistance of Messrs. A. Kular and A. Taylor for metallography and Mrs. V. Moore for electron probe microanalysis is also gratefully acknowledged.

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Table 1 - Casting conditions for single roll strip casting of type 304* stainless steel and aluminum-killed low-carbon steel**

SR #	Melt No.	Tapping temp ℃	Ladle temp ℃	Strip thickness mm	Strip quality	Comments
11	2808	1625	--			No strips could be produced
11	2808	1645		0.8	Ripples on the surface of strips	2-3 m of strip obtained
12	2820	1670		0.8	-do-	20 rpm wheel speed; metal frozen after a couple of metres strip; steel remelted and cast again at the same temp; more strips obtained
13	2850	1650	1628	0.7	-do-	Very thin zircon wash on wheel; lot of strips obtained (12-14 m)
14	2859	1650	1590	0.9	-do-	Very thin zircon wash on wheel; About 10 m of strips obtained; refractory tip at the tundish lip
15	2866	1650	1598	0.9	-do-	About 6 m of strip obtained
16	2869	1650	1580	1-2	Fewer ripples	Tundish level raised; 60° angle with the wheel; about 8 m of strips obtained; wheel speed was reduced towards the end to produce 2 mm thick strip
17	2874	1715	1680	0.9	Oxidation, strip not very flat	No wash; 60° angle of tundish with the wheel, 50 rpm; about 9 m of strip obtained
18	2883	1680	1615	0.8	-do- straight edge	30 rpm; tundish position as in #17 only 1 m of strip obtained
19	2895	1680	1600	0.9		Tundish opening reduced; it did not help to increase strip thickness; 50 rpm; 3-4 m of strips obtained
20	2897	1670	1603	--	--	Did not run well

* Run #11-16

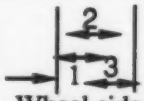
** Run #17-20

Table 2 Chemical Analyses of Steels produced in the Single-roll Caster

SR#	melt#	C	Cr	Ni	Si	Mn	S	P	Al	comment
11	2808	0.096	16.200	8.800	0.840	0.760	-	-		stainless steel
12 - 1	2820	0.080	17.000	8.300	0.810	-	0.015	0.013		stainless steel
12 - 2	2820	0.097	17.000	8.300	0.770	0.920	0.015	0.014		2nd attempt
13	2850	0.091	17.100	7.300	0.830	1.000	0.016	0.010		stainless steel
14	2859	0.150	15.600	7.100	0.820	0.840	0.013	0.016		stainless steel
15	2866	0.120	16.700	7.900	0.860	0.950	-	-		stainless steel
16	2869	0.120	17.300	7.700	0.800	0.860	0.013	0.013		stainless steel
17	2876	0.069	-	-	0.170	0.220	6.0E-03	0.010		low C steel
18	2883	0.042	-	-	0.150	0.210	6.0E-03	5.0E-03	0.090	low C steel
19	2895	0.036	-	-	0.230	0.240	6.7E-03	7.2E-03	0.083	low C steel
20	2897	0.027	-	-	0.190	0.180	7.1E-03	7.1E-03	0.130	low C steel
specifications for 304 stainless steel		0.08 max	18 to 20	8 to 10.5	1.0 max	2.0 max	0.03 max	0.045 max		
requirements for * Al-killed low C steel		0.05 max				0.3 max	0.018 max	0.01 max	0.05 max	

* 0.006 % maximum nitrogen

Table 3 - Range of Cr and Ni contents in 304 stainless steel strip produced in the single-roll caster (Run #16*)

Specimen thickness mm	Chromium, wt %			Nickel, wt %			Comments
	Next to wheel (1)	Middle (2)	Upper (3)	Next to wheel	Middle	Upper	
2	16-19	15-23	16-21	5-8.5	5-8	4-8	Wheel side
2	16-19	16.5-20.5	16.5-21	5-7.5	5-8	3.5-8	 Wheel side
1	16-19	16-19	16-19.5	5.5-8	5-8	5-8	Wheel side

* Composition of strip is 17.3 Cr and 7.7 Ni.

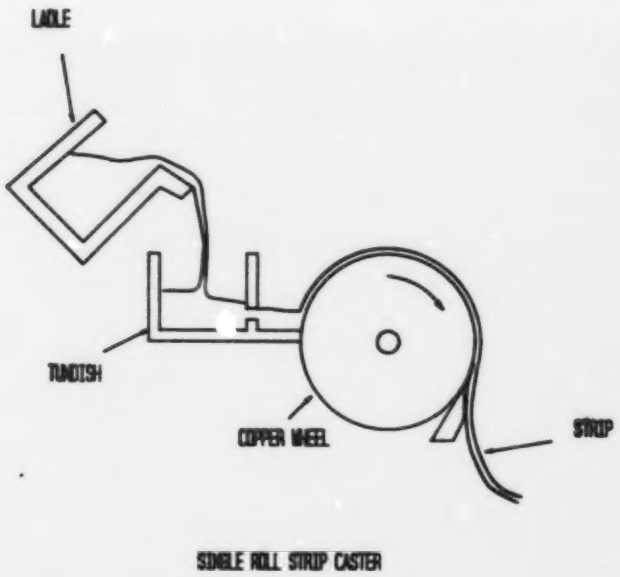


Fig. 1 - Schematic representation of single-roll strip casting unit. (neg 17771)

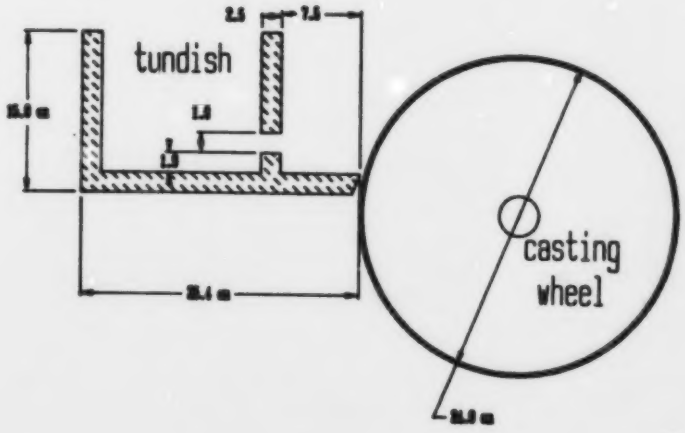


Fig. 2 - Schematic representation of the copper wheel and tundish set-up. The tundish is about 13 cm wide. (neg 17772)

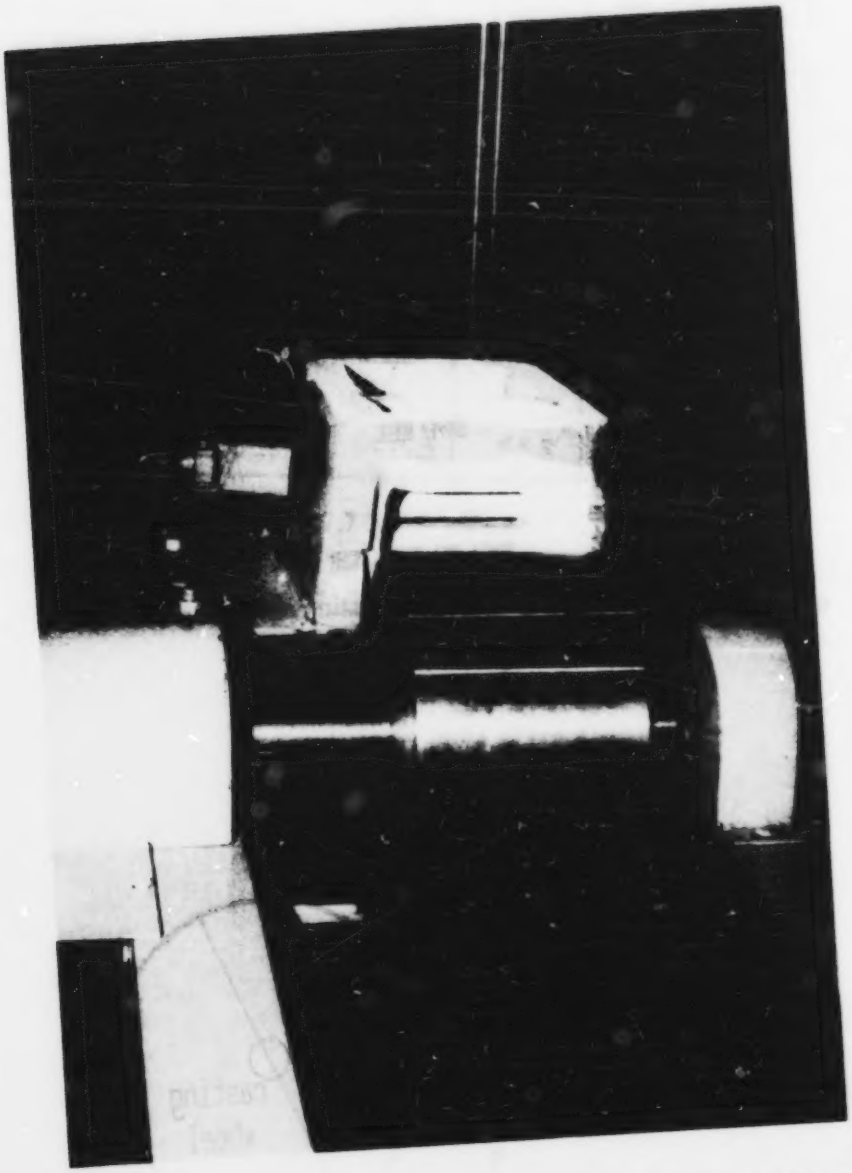


Fig. 3 - Close-up view of the copper wheel and tundish. The tundish is raised to a higher level to show the inner details. (neg 15962, 12A)

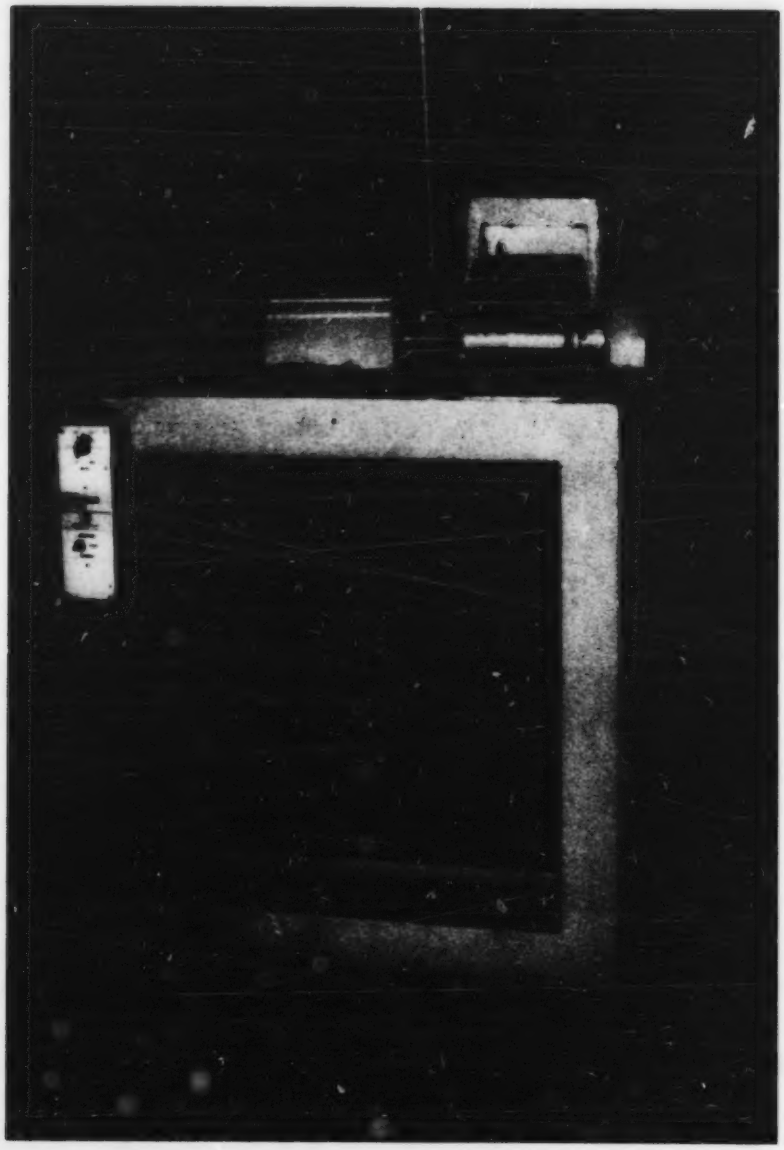


Fig. 4 - CANMET's single-roll strip caster. (neg 15965, 5A)

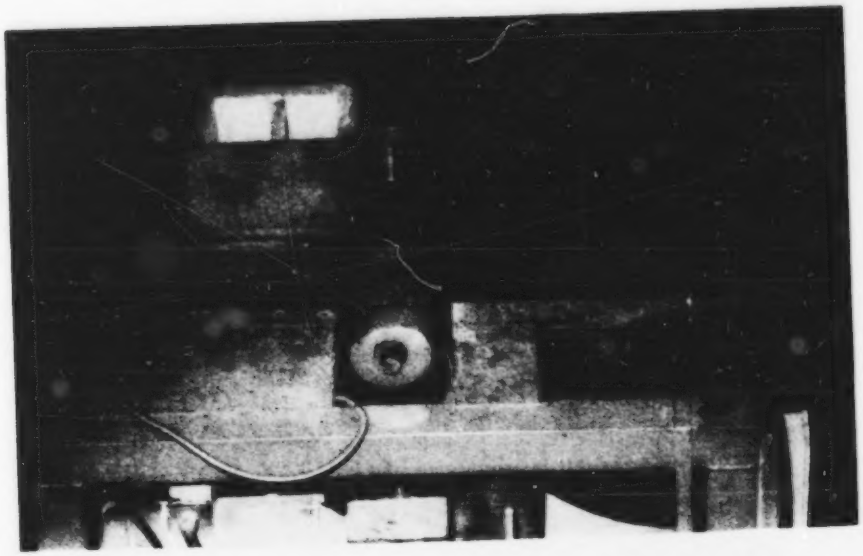


Fig. 5 - Single roll strip caster showing the tundish, copper wheel and the cover for maintaining a protective atmosphere. (neg 17668, 13A)

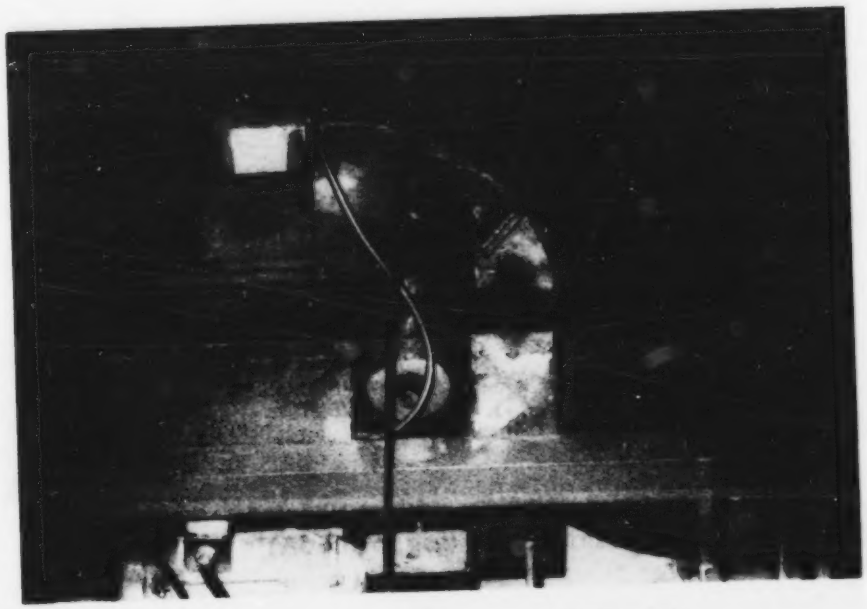


Fig. 6 - Cover for argon flushing during strip casting. (neg 17668, 10A)

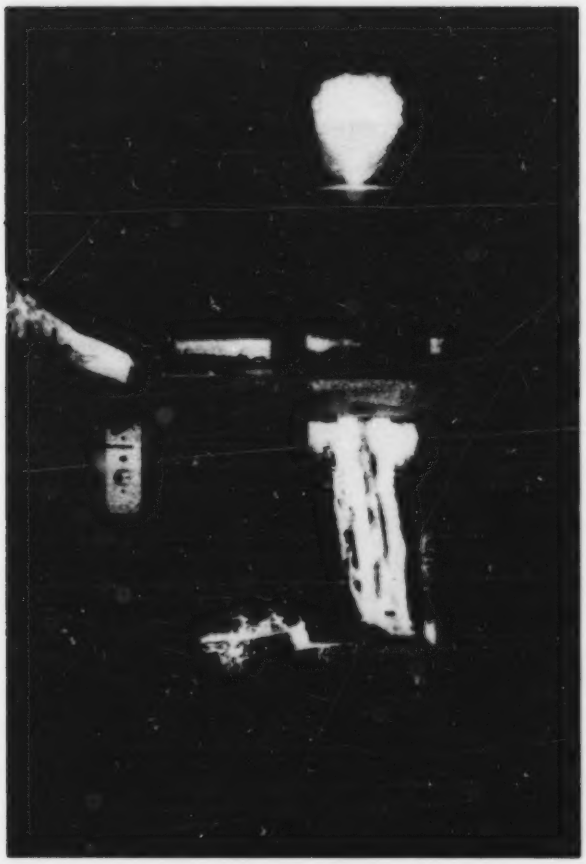


Fig. 7 - Single roll strip casting machine in operation showing (a) liquid metal (304 stainless steel) being poured into the tundish, (b) protective cover for argon shielding and (c) strips lying on the floor. (neg 17668, 25A)

Fig. 8 - Use of brass wheel to produce smooth surface on the strip. (neg 17757)

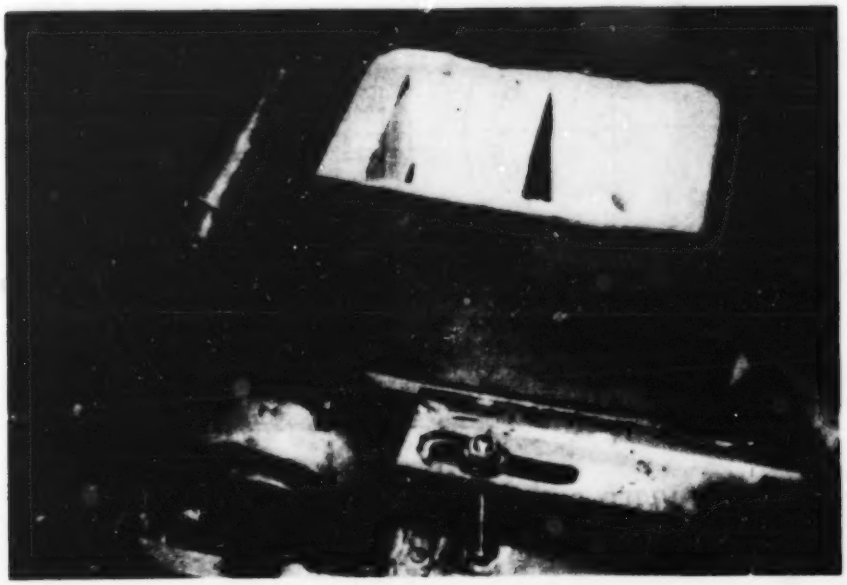


Fig. 9(a) - Brass wheel and the tundish. (neg 17757)

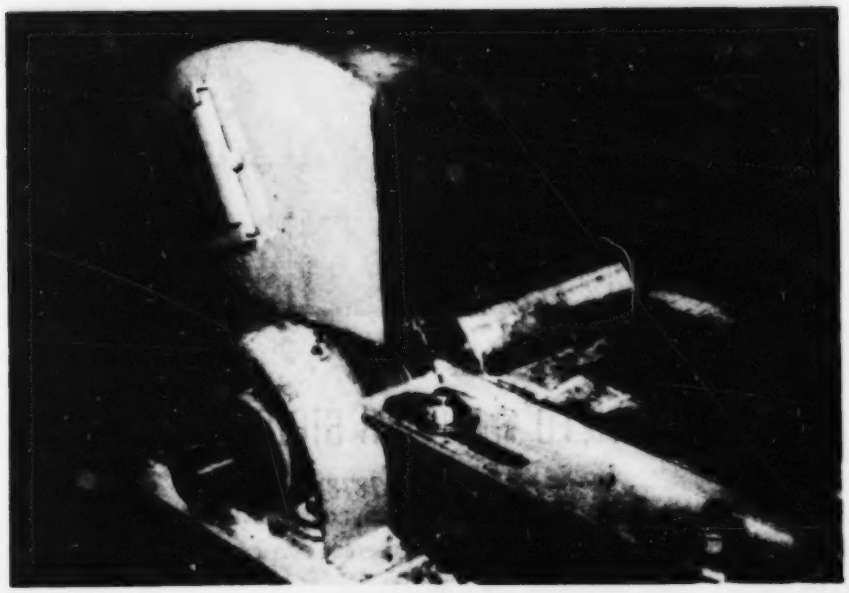
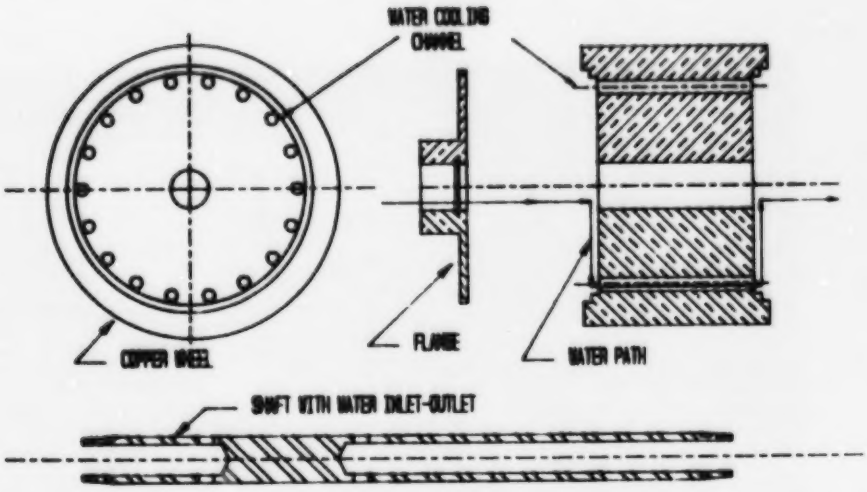
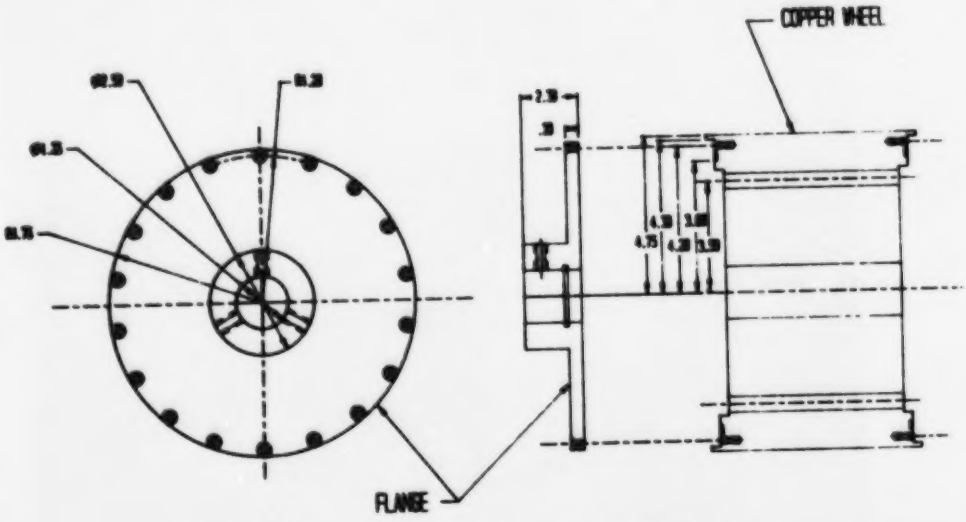


Fig. 9(b) - Brass wheel and the argon cover. Tundish has been removed for clarity. (neg 17757)



WATER COOLED WHEEL FOR STRIP CASTING

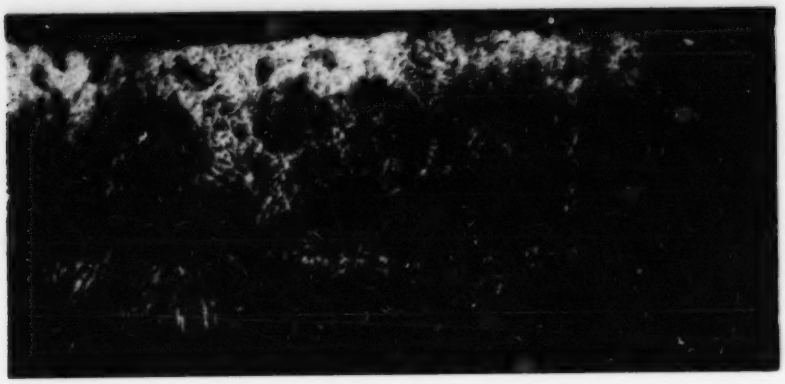
(a) (neg 17879)



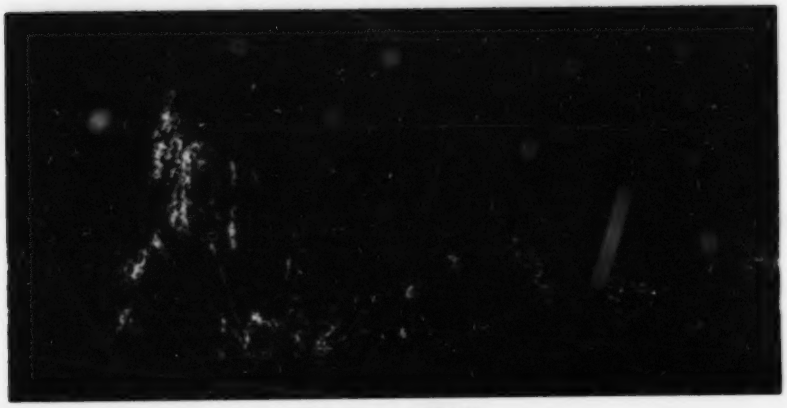
WATER COOLED WHEEL FOR STRIP CASTING

(b) (neg 17878)

Fig. 10 - Water cooled wheel assembly for strip casting.

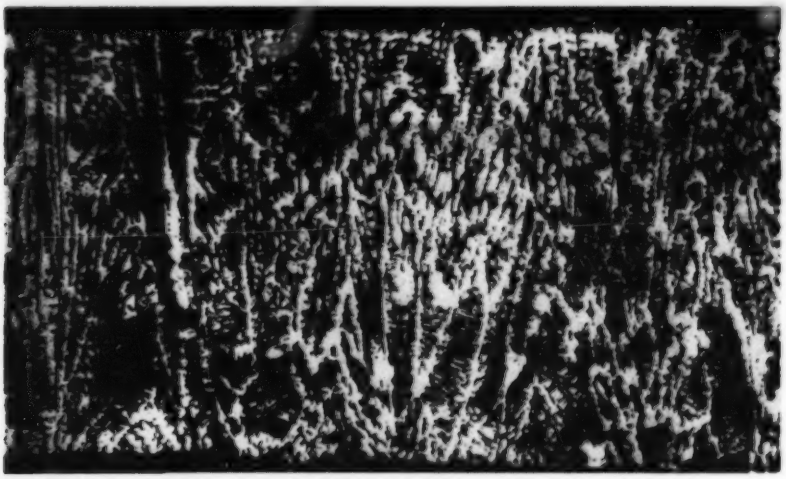


(a) (neg 17933)

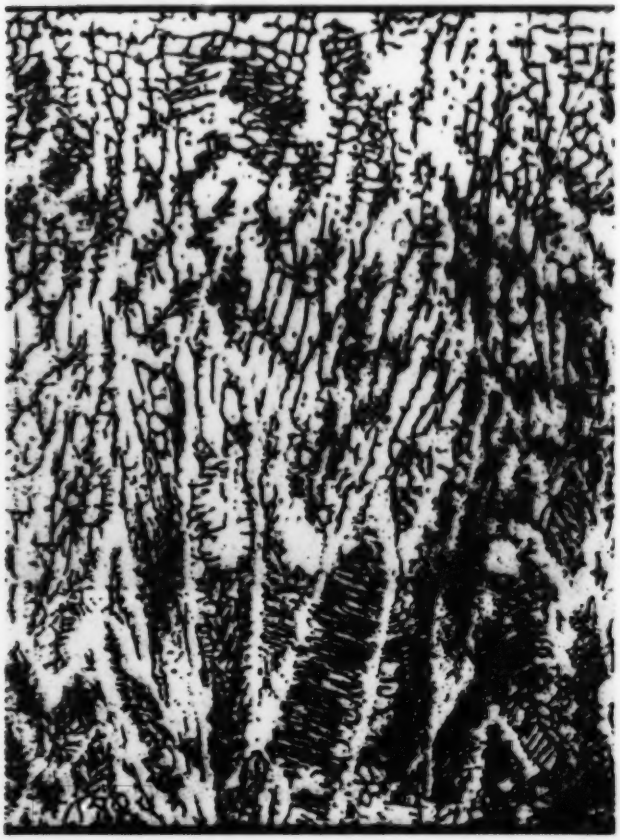


(b) (neg 17934)

Fig. 11 - Optical micrographs of the transverse section of 304 stainless steel strip, Run #11. Etched in a solution of 55 mL acetone, 40 mL HCl and 5 g copper nitrate. 100x.

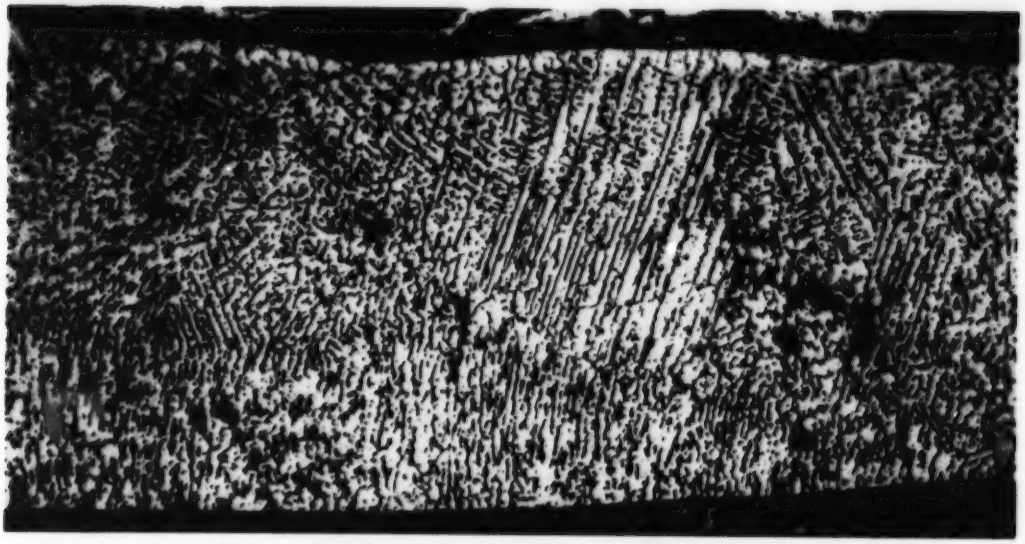


(a) 100x (neg 17935)

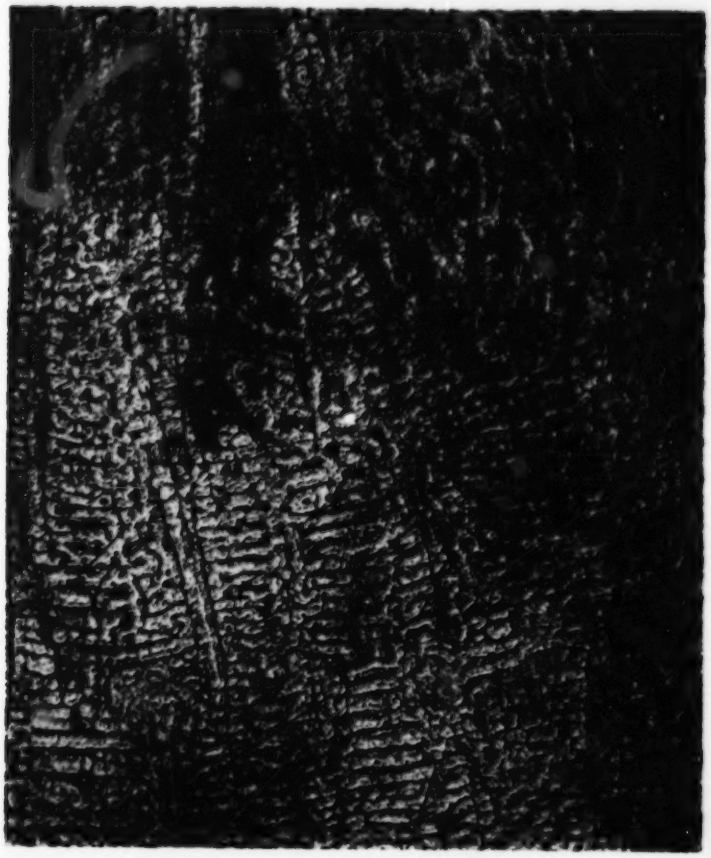


(b) 200x (neg 17936)

Fig. 12 - Optical micrographs of the transverse sections of 304 stainless steel strip, Run #12. Etched in a solution containing 55 mL acetone, 40 mL HCl and 5 g copper nitrate.



(a) Thin section, 100x (neg 17937)



(b) Thick section, 200x (neg 17938)

Fig. 13 - Optical micrographs of the transverse sections of 304 stainless steel strip, Run #16. Etched in a solution containing 55 mL acetone, 40 mL HCl and 5 g copper nitrate.

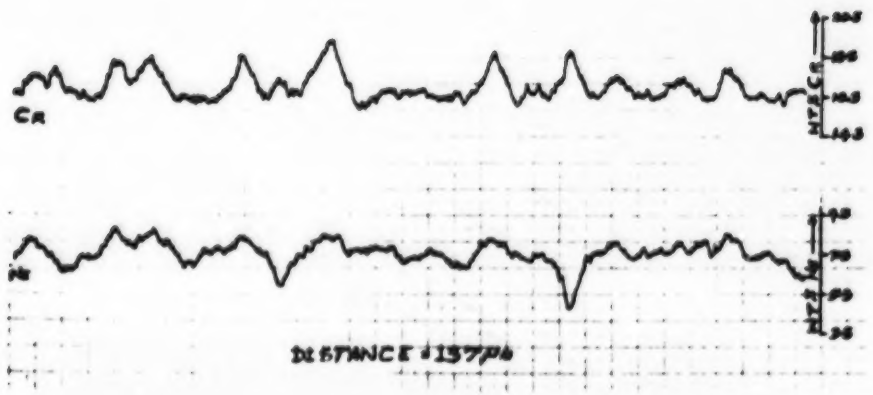


Fig. 14 - Trace of electron probe showing the variation in Ni and Cr contents in the transverse sections of the thin strip (Run #16) over a distance of 157 μm. Strip surface in contact with the copper wheel. (neg 17781)

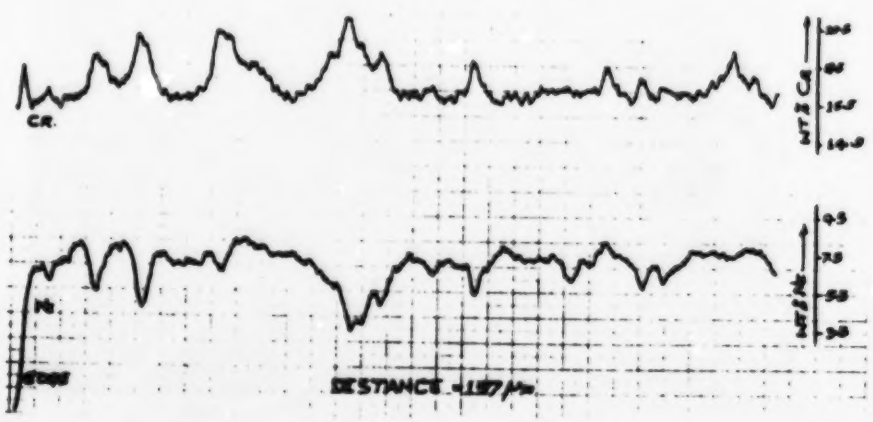
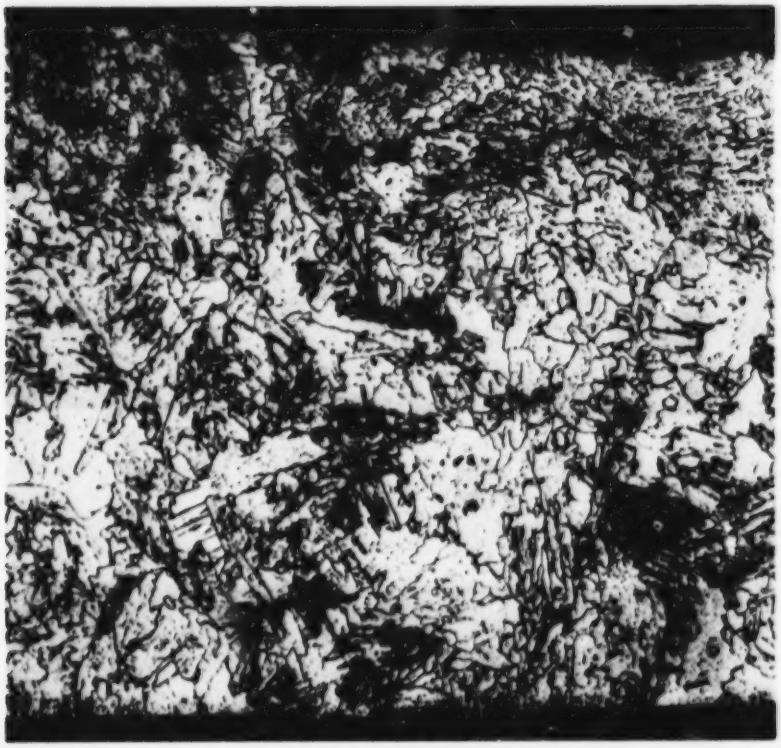
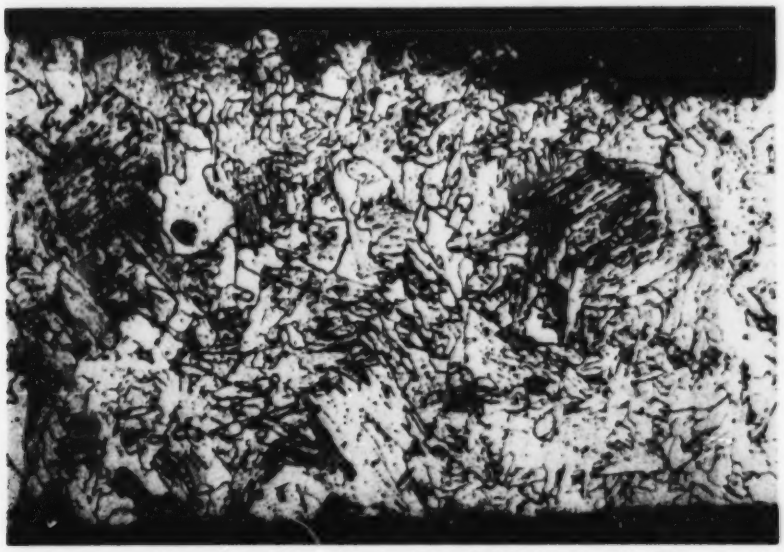


Fig. 15 - Trace of electron probe showing the variation in Ni and Cr contents in the transverse sections of the thick strip (Run #16) over a distance of 157 μm. Strip surface in contact with the copper wheel. (neg 17782)

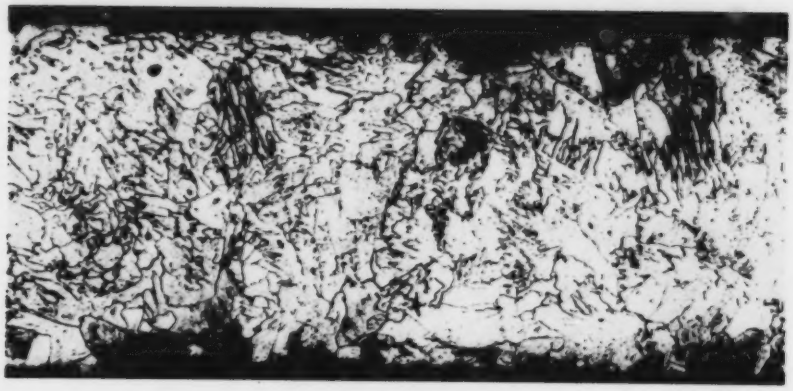


(a) thick section (neg 17940)



(b) thin section (neg 17939)

Fig. 16 - Optical micrographs of the transverse sections of aluminum-killed low-carbon steel (Run #17). Etched in 2% nital. 100x



(a) 100x (neg 17941)

(b) 200x (neg 17942)

Fig. 17 - Optical micrographs of the transverse sections of aluminum-killed low-carbon steel (Run #18). Etched in 2% nital.